Phosphorus and algae growth in Utah Lake

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Nutrients, algal growth and water quality impacts?

—the genesis of Utah's WWTP nutrient controversy.

Eutrophication:

Increasing aquatic plant growth and overall biological productivity in a water body over time.

More “water quality problems” often occur with increasing eutrophication of a water.

Natural eutrophication for a lake to go from pristine lake to a swamp often takes thousands of years, or more—sometimes human activities accelerate this natural process.

Trophic level classification of lakes:

	Biomass	Clarity
– Oligotrophic	low bio-productivity	clear
– Mesotrophic	moderate “	slightly turbid
– Eutrophic	high “	turbid
– Hyper eutrophic	very high “	very turbid

Turbidity as used here is biological turbidity

- Oligotrophic lake

- Mesotrophic lakes

- Eutrophic lakes

- Hyper-eutrophic lakes

- Most lakes eventually become marshland—then wet meadows—then “basin” land

Water quality “problems” in lakes, particularly Eutrophic lakes

- *Turbidity:* *Cloudy water from algae and other biota*
- *Aesthetics:* *General unsightly conditions near and in the water*
- *Shoreline Debris:* *Unsightly bio-debris accumulation*
- *Oxygen Loss:* *Normal biota stressed, sometimes killed*
- *Mucky Bottom:* *Murky, often septic, bottom conditions*
- *Bad odors:* *Decaying bio-matter*
- *Nuisance Insects:* *Swarms of insects and aquatic bugs*
- *Coarser Fish:* *Conditions favor “coarser” fish and other aquatic life*
- *Toxics:* *Mainly from cyanobacteria decay*

Important to Note—

- Most "problems" in eutrophic waters relate to on-site *aesthetics and recreation*—and generally not to fundamental concerns with disease and filth.

- That is, many eutrophic issues relate to
  - **"How pristine and scenic is the lake (or river)?"**
  - **"Is it pleasant to be around, are there any bad odors?"**

- *Even some Oligotrophic and many Mesotrophic lakes/reservoirs have some of the problems associated with "eutrophic" conditions, but eutrophic lakes usually have more problems that are more persistent.*

- *Rivers/steams can also have algae-caused water quality problems but usually to a lesser extent that lakes do.*

So what's best? *Lake Tahoe*

0r Strawberry Reservoir

Lake Eutrophication

So what's best?

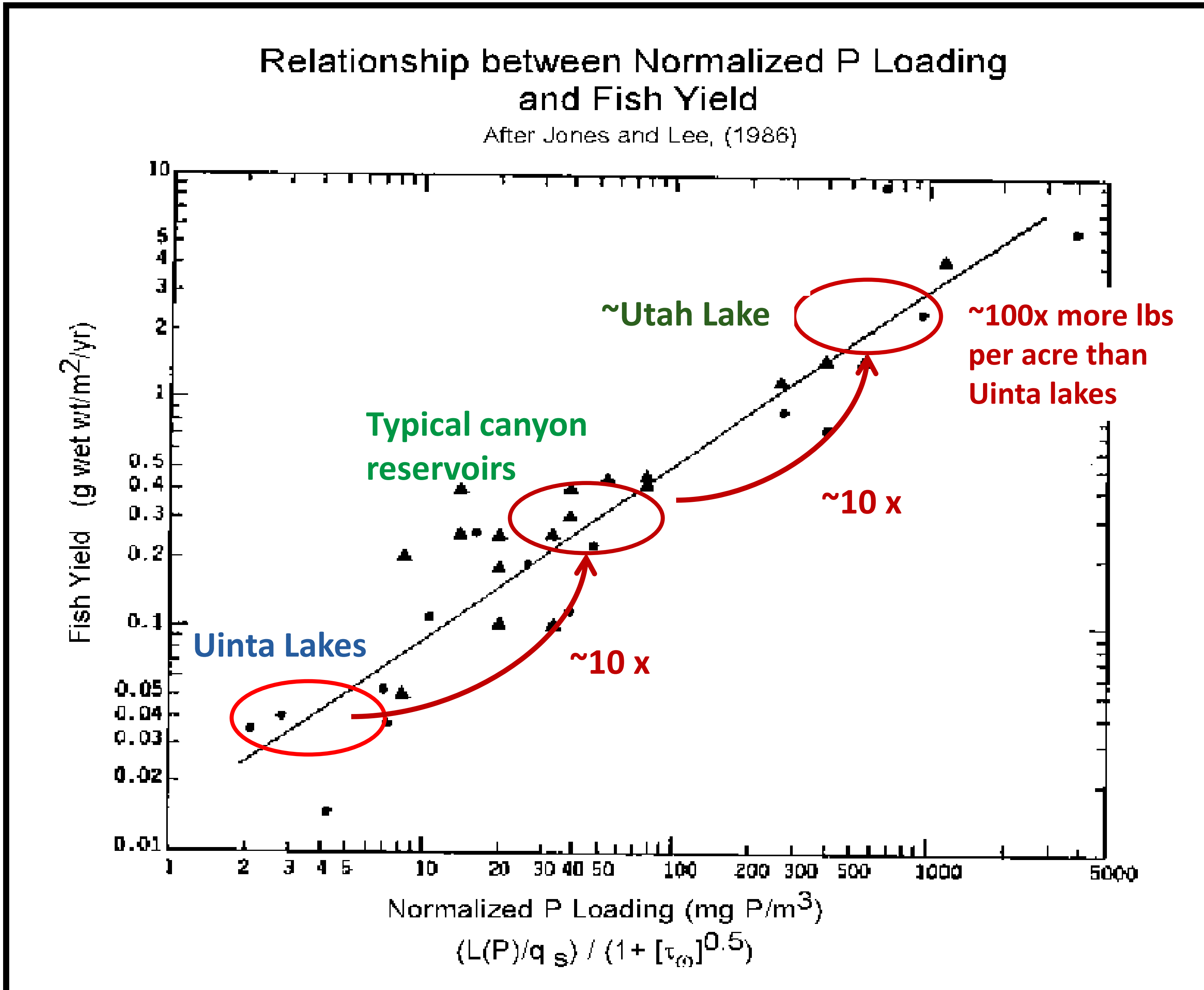
Lake Tahoe

or

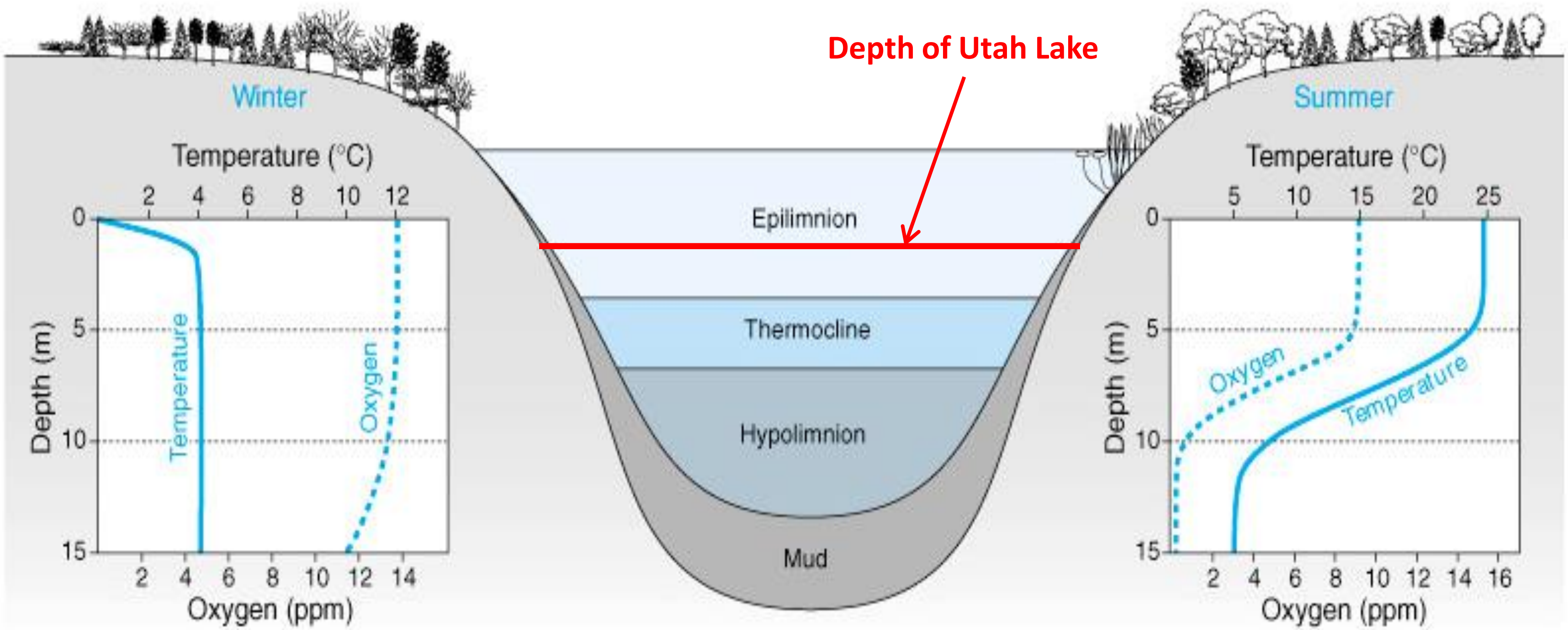
Strawberry Reservoir

Ans–

To a large degree it's how 'Mother Nature' made them and personal cultural perception of various use values.


Relationship between Normalized P Loading
and Fish Yield
After Jones and Lee, (1986)
Fish Yield (g wet wt/m2/yr)
Normalized P Loading (mg P/m3)
(L(P)/q s) / (1+ [τω]0.5)
10
5
4
3
2
1
0.5
0.4
0.3
0.2
0.1
0.05
0.04
0.03
0.02
0.01
1
2
3
4
5
10
20
30 40 50
100
200 300
500
1000
5000
~Utah Lake
~100x more lbs
per acre than
Uinta lakes
Typical canyon
reservoirs
~10 x
~10 x
Uinta Lakes

“Deep” Eutrophic Lake



Strawberry Reservoir—1975-76

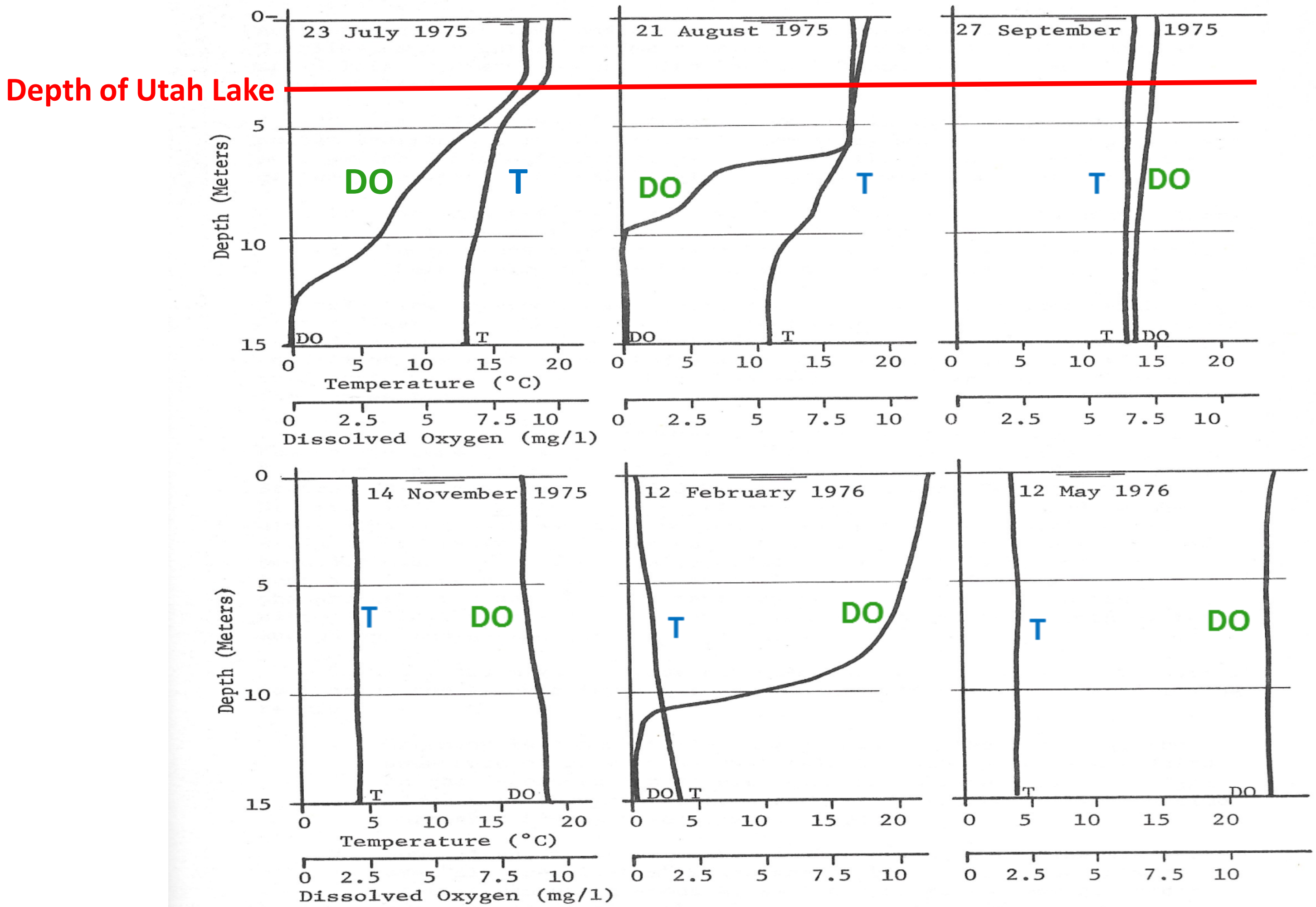


Figure 7.11. Strawberry Reservoir – Observed Temperature and Oxygen Profiles at Station SB-3, 23 July 1975 to 12 May 1976.

What about eutrophic problems in Utah Lake?

- *Turbidity:* *major —mainly mineral turbidity*
  —biological turbidity usually moderate
- *Aesthetics:* *moderate*
- *Shoreline Debris:* *moderate*
- *Oxygen Loss:* *rare*
- *Mucky Bottom:* *mainly mineral--less organic*
- *Bad odors:* *moderate*
- *Nuisance Insects:* *moderate*
- *Coarser Fish:* *yes but—largely not water quality related*
- *Toxics:* *low*

All in all:

Utah Lake has much better "water quality" than most alkaline, eutrophic, shallow, basin-bottom lakes!

–most such lakes experience very heavy algal blooms and are rather undesirable for most recreation uses.

Why is Utah Lake better?

- Inflowing water is generally of good quality, but fairly hard and alkaline
- Deep enough to provide good habitat and avoid extremely high temperatures
- Shallow enough avoid persistent density stratification (temperature or salinity
- Large enough to have rather high waves that keep the water well oxygenated
- Its characteristics moderate heavy algal growth most of the time (turbidty)

The Big question

–could Utah Lake be even "better" than now?

Concept of Limiting Factors

—At any given time some growth factor is controlling growth.

- Light (Amt. of sunshine reaching the algae)
- Nutrients (phosphorus, nitrogen, other trace minerals)
- Temperature (rate and "health" of growth)
- Time (time duration of set of conditions)
- Toxicants (that inhibit algal growth)
- Variability in factors
- Competition
- Grazing/Harvesting

Usually

- Light
- Nutrients
- Temperature
- Time
- Toxicants
- Variability in factors
- Competition
- Grazing/Harvesting

Utah Lake’s natural condition:

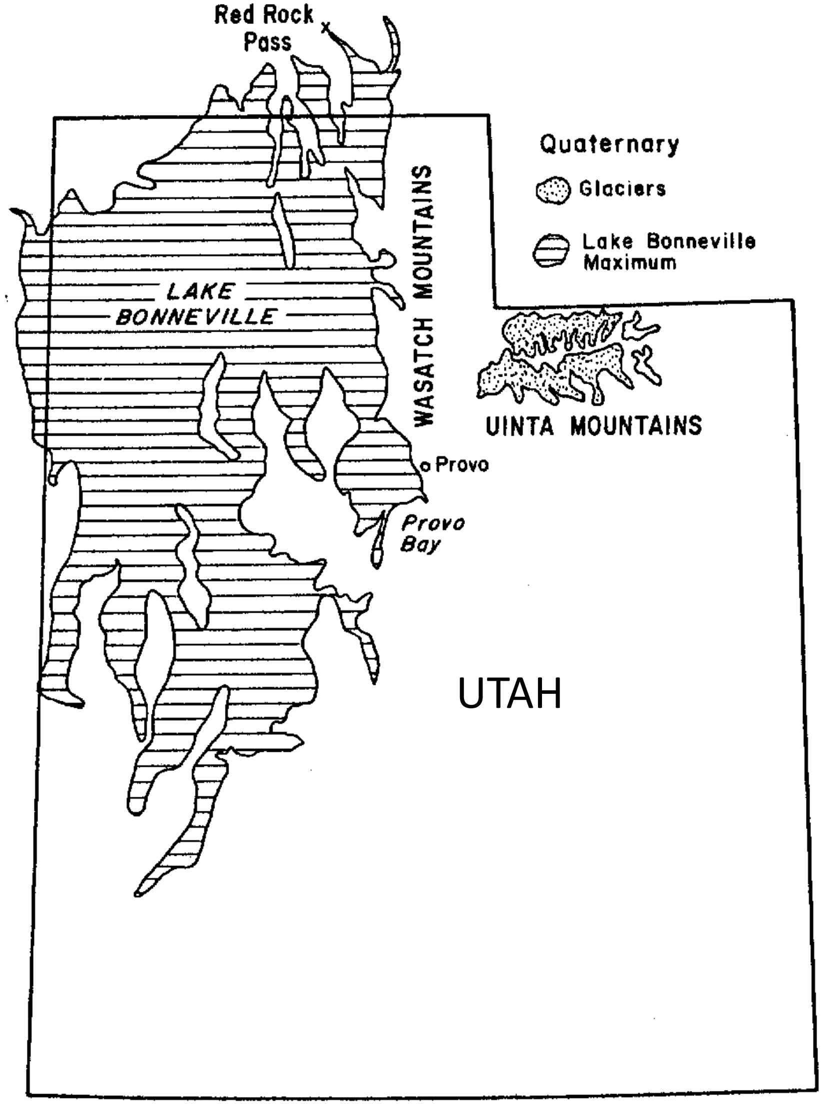
- shallow
- Alkaline & slightly saline
- turbid (cloudy from suspended precipitates)
- eutrophic
- in semi-arid region

Indications are that the lake has been essentially this way since it stabilized after Lake Bonneville last receded 8000 to10,000 yrs ago.

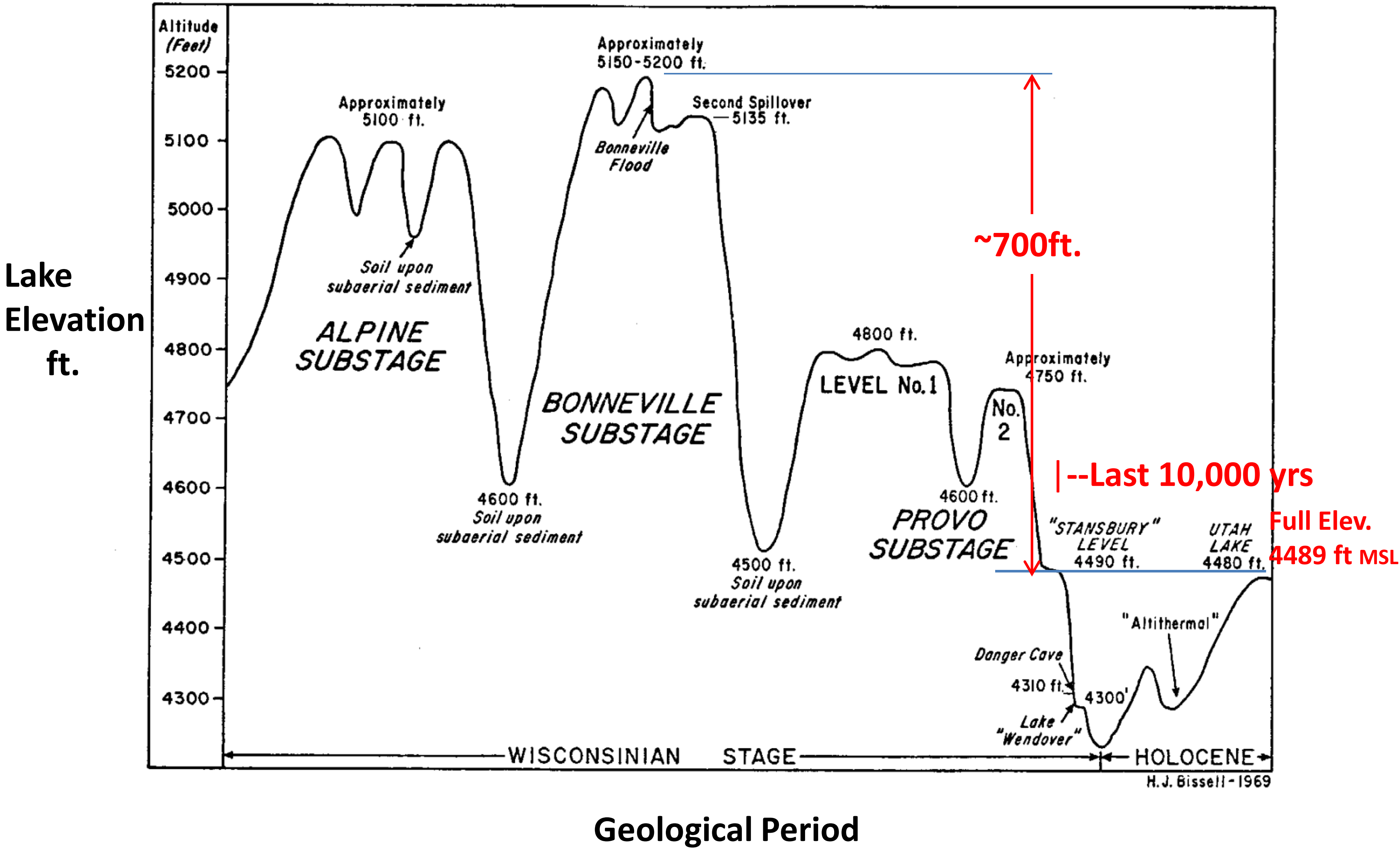
Utah Lake's Origins

Lake Bonneville

(A few hundred thousand years ago)



Utah Lake's Origin: --Remnant of Lake Bonneville.



Utah Lake during a windy period

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Turbidity in Utah Lake

Table 1. Utah Lake Inflows: Avg Salt and Water Quantities for 2009-2013.

I. INFLOW	Flow		Percent of Inflowing S a l t s								% of Nutrients		
1. **Surface**	af/yr	%	TDS	Na	Ca	Mg	K	Cl	HCO3	SO4	TP	DN	DP
a. Mtn Strms	287862.	52.0	24.3	12.9	42.5	28.3	14.5	10.0	39.6	19.6	7.0	14.5	4.2
b. WWTP	53126.	9.6	11.0	12.9	8.9	9.0	14.2	14.3	10.4	6.3	79.	54.7	85.5
c. Main L-other	77799.	14.1	17.3	12.4	16.6	24.1	15.2	9.8	22.1	27.8	7.6	17.5	6.2
d. Provo B-other	53232.	9.6	9.8	4.8	13.0	11.8	7.6	4.6	12.1	11.4	1.6	5.5	1.3
e. Gosh. B-other	23073.	4.2	14.0	24.1	3.2	10.1	17.5	23.7	3.4	14.3	1.6	2.3	1.5
1. Subtotal:	495092.	89.5	76.4	67.1	84.2	83.3	69.0	62.5	87.6	79.4	**96.8**	**94.6**	**98.7**
2. **Fresh Grnd water**													
a. Main L-gw	31640.	5.7	3.3	1.9	3.9	5.2	3.4	1.7	5.2	2.7	0.4	1.8	0.3
b. Gosh. B-gw	11531.	2.1	3.0	3.4	2.1	3.9	4.7	3.8	2.3	2.9	0.1	0.7	0.1
2. Subtotal:	43171.	7.8	6.2	5.2	6.0	9.0	8.0	5.4	7.5	5.6	0.5	2.4	0.4
3. **Thermal/Mineral GW**													
a. Main-min sprs	13957.	2.5	16.7	26.8	9.5	7.0	22.6	31.1	4.6	14.5	0.3	0.1	0.3
b. Gosh. B-m sprs	787.	0.1	0.3	0.6	0.1	0.1	0.4	0.5	0.1	0.4	0.0	0.0	0.0
3. Subtotal:	14744.	2.7	17.1	27.4	9.6	7.2	23.0	31.6	4.7	14.9	0.4	0.1	0.3
1,2& 3 subtot	553007.	100.0	99.7	99.8	99.8	99.5	100.0	99.5	99.9	99.9	97.7	97.0	99.4
4. **Precipitation**													
a. Main Lake	52884.	b. Provo Bay 8633. c. Goshen Bay 31649.											
4.Total Precip	93164.		0.3	0.2	0.2	0.5	0.1	0.5	0.1	0.1	2.3	3.0	0.6
			100.	100.	100.	100.	100.	100.	100.	100.	100.	100.	100.

INFLOW TOTAL 646,171.

II. **Outflow.**

1. **Jordan River** 336,045.

2. **Evaporation**

a. Main Lake 218073. b. Provo Bay 32133. c. Goshen Bay 92602.

2. Subtotal 332,808.

About 50% of the water evaporates

II. Outflow tot 668853.

Lake Storage -22682.

Net 646171.

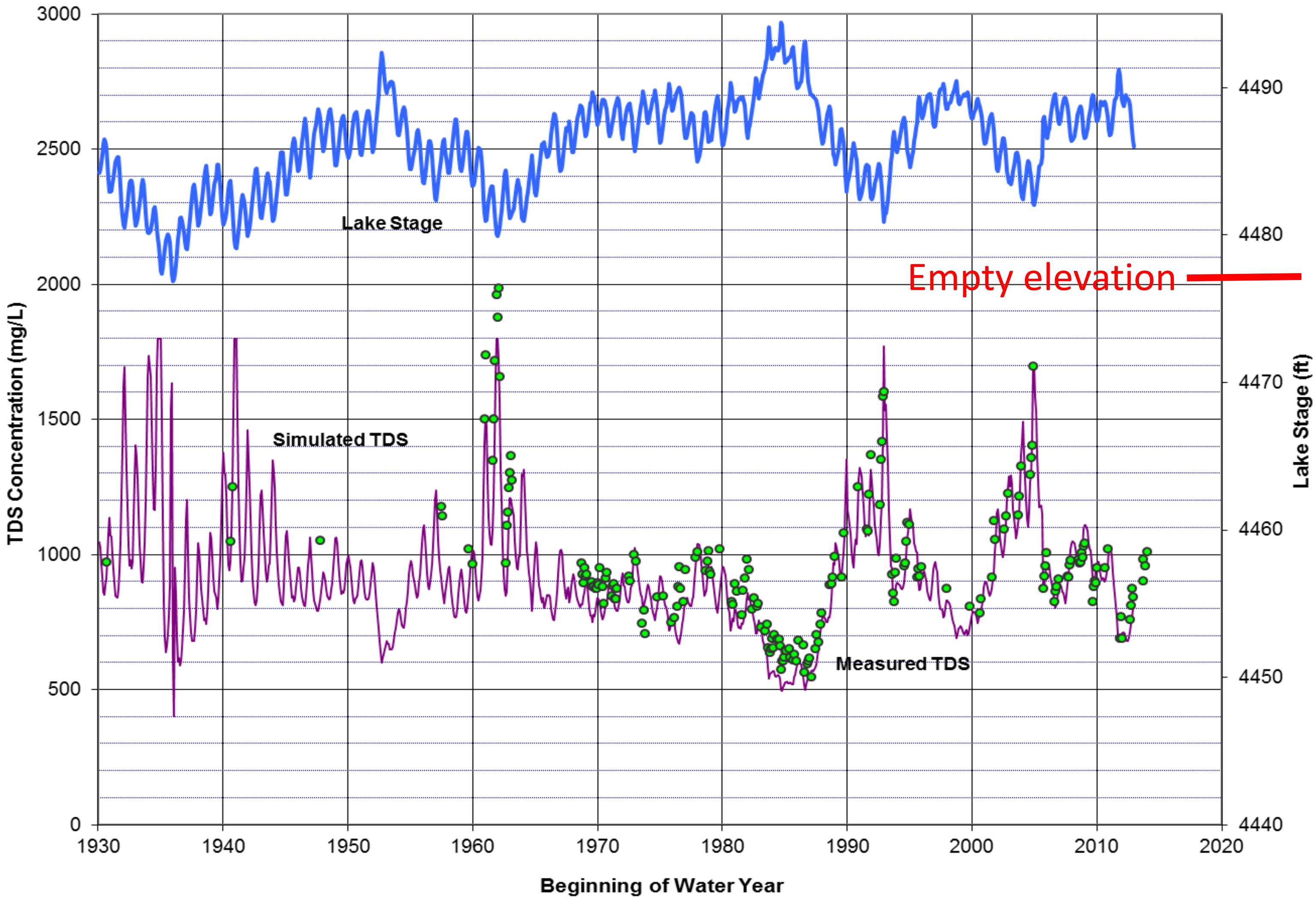
	TDS	Na	Ca	Mg	K	Cl	HCO3	SO4	TP	DN	DP
Ratio: salts out/salts in:	85.	108.	39.	107.	109.	110.	54.	110.	**9.4**	**17.1**	**9.4**

Approx. corrected

Table 1. Utah Lake Inflows: Avg Salt and Water Quantities for 2009-2013.

	TDS	Na	Ca	Mg	K	Cl	HCO3	SO4	TP	DN	DP
Percentage: (salts out/salts in)	79	100	36	100	100	100	50	100	9	16	9

The Ca and HCO3 precipitated averages about 100,000 tons /yr
--this is about 2”/100 yr over the full-lake area!
--or about 200” (18 ft) in 10,000 yrs.



Historical Total Dissolved Solids and Water Levels in Utah Lake

Utah Lake has high natural turbidity, Why?

1. In-lake chemical precipitation of calcium-carbonate-silica-phosphorus adds a natural, cloudy, mineral turbidity.

   (removes some 100,000 tons/yr--this is an avg. of about 2 in. of bottom sediments per 100 yrs.—3” or 4” in deeper areas)

Resulting Secchi Disk readings –light penetration.

Typically at about 3x the Secchi depth there isn’t enough light for algal growth. During the summer, Secchi depths in Utah Lake are usually only a few tenths of a foot --indicating very high turbidity and very limited algal growth below about 1 ft. deep.

This turbidity significantly limits algal growth!

Light limitation Cont.

2. Frequent waves in shallow Utah Lake tend stir up and re-suspend previously precipitated sediments giving turbid, light-limiting, algal-growth conditions much/most? of the time.

Ans:

Overall, Utah Lake algal growth is likely light-limited.

If this is the case, **nutrients are not the answer** and removing or adding more is of little consequence to algal growth.

The Current Issue!

The DWQ has (de facto) assumed that nutrients are a big problem and we must remove them!

The impact of Utah Lake WWTP nutrients? –Do they cause more algal growth?

That is—

Are P & N limiting, or could be made limiting, to algal growth?

—will nutrient removal reduce growth?

To answer this question—need to consider:

1. Observed actual in-lake conditions?
2. Predicted conditions from Trophic State models?

1. What is the actual in-lake trophic condition?

Carlson Trophic State Index (Utah Lake in red)

Trophic Index	Chl a (ug/l)	P (ug/l)	Secchi Disk (m)	Trophic Class
<30—40	0—2.6	0—12	>8—4	Oligotrophic
40—50	2.6—20	12—24	4—2	Mesotrophic
50—70	20—60	**25—100**	2—0.5	**Eutrophic**
70—100+	**60—155+**	96—384+	**0.5—<0.25**	Hyper-eutrophic

In Utah Lake, the hyper-eutrophic level from Secchi Disk readings is a compromised indicator since it is mainly from mineral turbidity, not biological turbidity.

Conclusion:

- Based on in-lake observations/samples:

The actual biological status of Utah Lake is moderately eutrophic.

2. Trophic state models.

Larsen-Mercier Trophic State Model

- *By EPA scientists—improvement of the classic Vollenweider Model.*
- *Based on assumption that phosphorus is the limiting growth factor.*

Model data:

- Annual avg. conc. of phosphorus in inflowing water.
- Retention coeff. — based on water residence time and depth.

Predicts the expected lake trophic level.

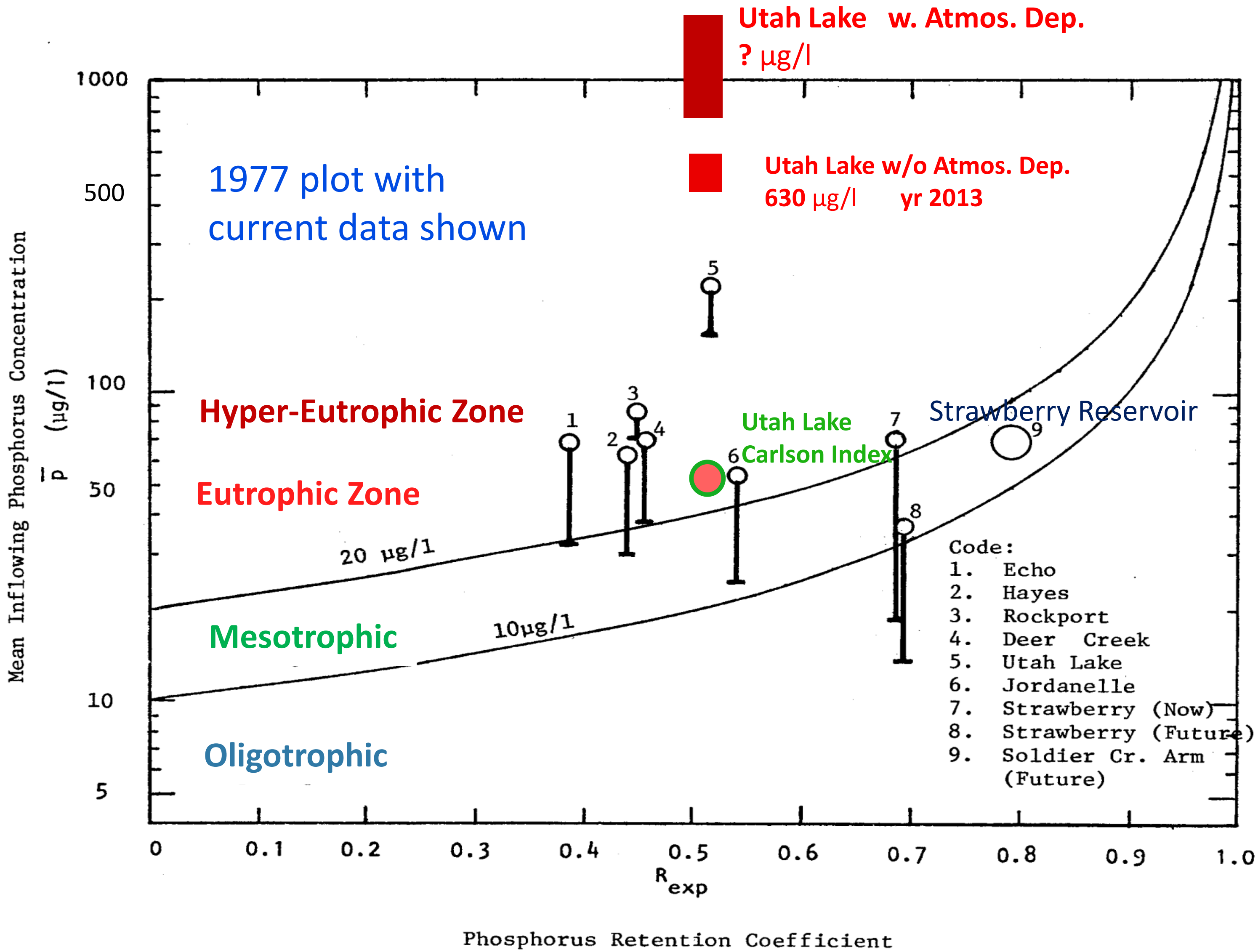
--but only if phosphorus is the overall controlling/limiting factor !!!

(Caution: Often doesn't apply to strongly/hyper eutrophic systems since other growth factors, not phosphorus, may be the most limiting factors to algae.)

Table 3. Nutrient Loadings to Utah Lake by water year, 2009 – 2013 (w/o Atmos. D.)

Water Year	Phos. tons/yr	SRP tons/yr	Nitrogen tons/yr
2009	277	232	2235
2010	257	219	1813
2011	327	267	2872
2012	247	211	1812
2013	252	216	1816
Average	**272**	**229**	**2145**

272 tons in avg Utah Lake inflow gives 634 µg/l:
(loading into the net amount of water in the lake,
About one half of the water is lost via evaporation.)



Predicted Trophic State based on the Larsen-Mercier Model

Is P limiting?

Ans: The L-M model predicts ultra. . .hyper eutrophic
but the actual level is just moderately eutrophic.

Therefore: Phos. Is likely not controlling (not limiting)!

Might P be made limiting? What is possible?

First—let's "wish away" the natural light-limiting turbidity and Atmos. Dep.

—and see if Phos. might be made limiting
(Hoped for response—reduce algae via P removal).

Might P be made limiting? What is possible?

- WWTPs: About 80% of the Lakes P loading from WWTPs

  (2013 loading not including atmos. deposition, but note that AD is very large.)

  – 90-95% removal at WWTPs.

    - means some $400-$600? millions in construction costs and tens of millions in annual O&M costs. It would likely double to quadruple sewerage fees.

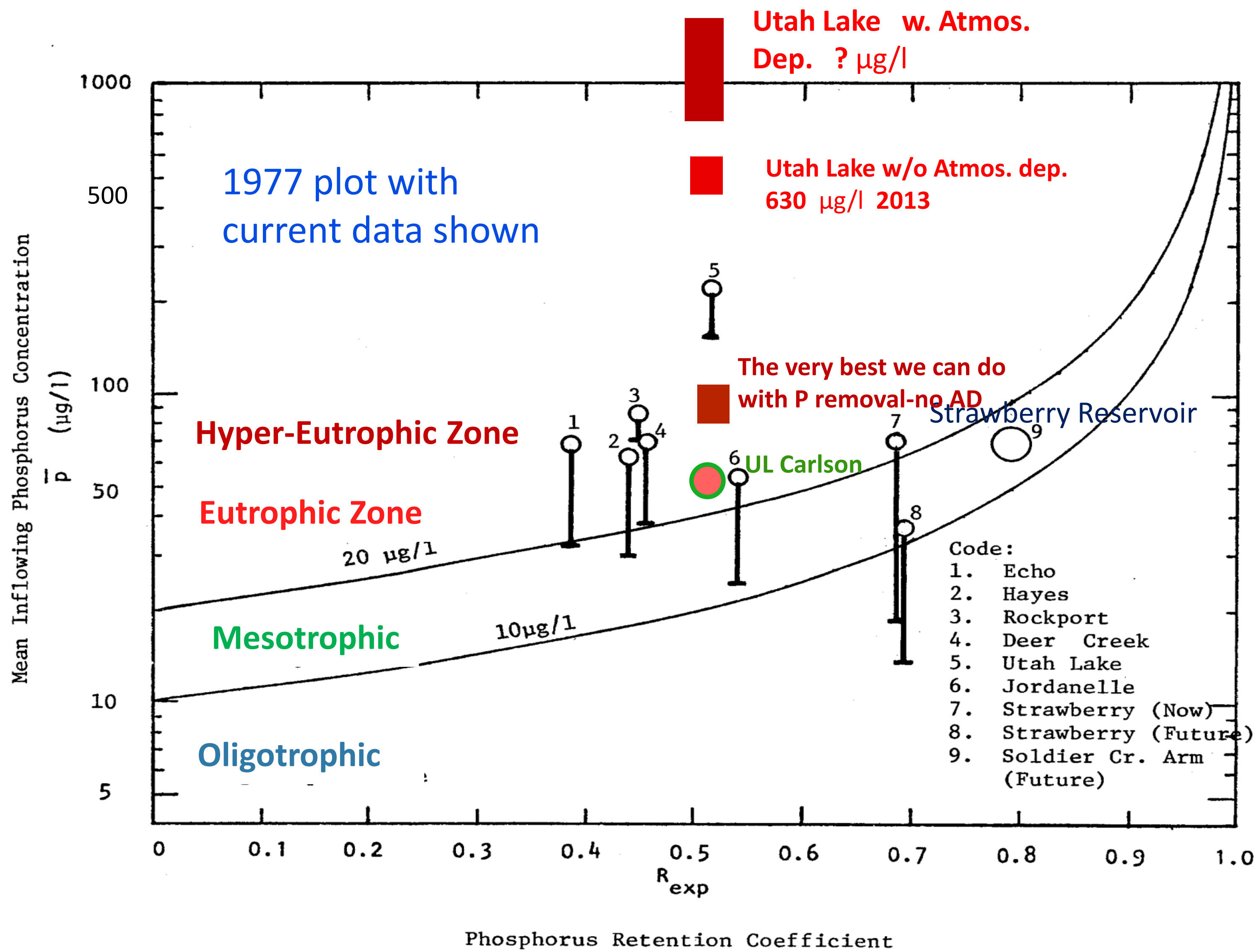
- Nonpoint sources (NPS)—

  – Maybe 25% of the remaining non-AD Phos. <u>might</u> be removed with rigorous NPS controls.

  – Costs would be staggering.

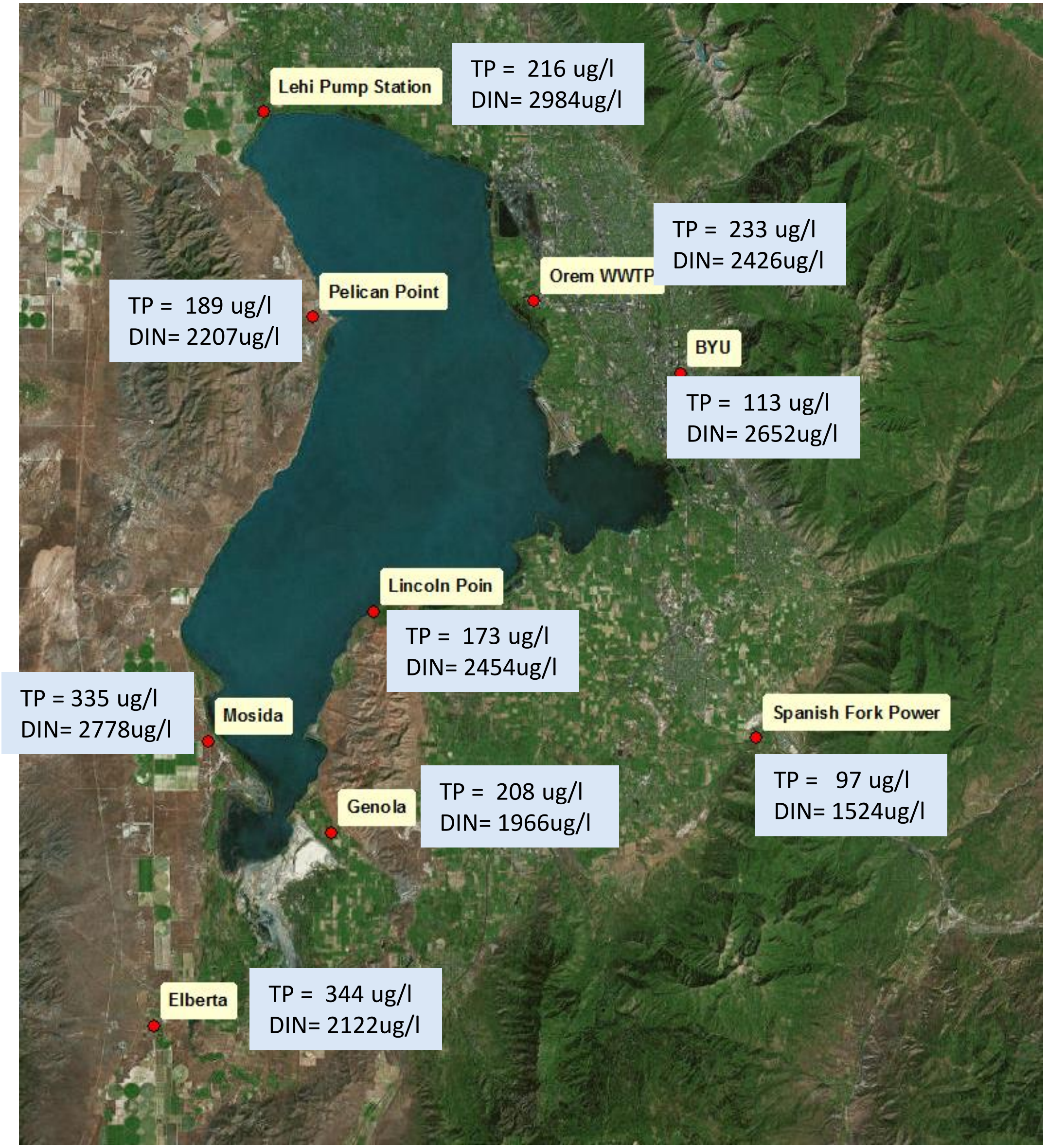
    - likely $10s of millions to get to a 25% reduction in all other non-AD phosphorus loadings to the lake.

- Result**:** **634** µg/l would go to about **100** µg/l, not counting AD.



Predicted Trophic State based on the Larsen-Mercier Model

Wet precipitation study (2016-2019)— Dr. Wood Miller (BYU)



Approx. 30 rain events over 17 months

Avg P = 212 µg/l

Avg N= 2346 µg/l

Considering: just the Wet Atmos. Dep.

Dr. Miller's samples:
In the rain water: avg P = 212 µg/l
avg N = 2346 µg/l

1 ft of rain into 9 ft water gives **21** µ**g/l P** added to the Lake water.
(10 times dilution) gives **235** µ**g/l N**

These are in-situ eutrophic levels! But dry (dust) Atmos. Dep. is much higher! giving at least several times higher than eutrophic loadings just from AD!

This means that even if the lake had no P and N from other sources, it would still receive enough from just the AD to give the lake several times a eutrophic supply of P and N!

Now back to the real Lake.

where is all the P going?

The actual phosphorus removal in the Lake is 90%+.

It goes mainly in mineral precipitation to the lake sediments.

The "take- away": *Utah Lake is not a normal lake as to phosphorus—it has "unlimited" capacity to trap P into the bottom sediments; "equilibrium" with bio-cycles and precipitated sediments commonly gives some 40 to 70 µg/l of P in the water--which is a strongly eutrophic predictor—but turbidity likely limits the lake to* ***moderately eutrophic****.*

Bottom Line: The lake is doing a better job of P removal than advanced treatment at WWTPs could ever do—and it's natural and Free!

The flip side is that bottom sediments also provide an essentially unlimited supply of phosphorus to some 40 to 70 µg/l in the lake.

Again—where is 90%+ of the inflowing Phosphorus going?

Since the Lake has:

- High pH
- High oxygen levels
- Abundant Calcium, Carbonate, Silica and Phosphorus.

Ans—To the sediments via mineral precipitation.

and

Precipitation of minerals reduces phosphorus to relatively low levels during the summer growth season.

—typically 40 to 70 µg/l—regardless of how much is entering the lake!

But even then phosphorus is not limiting algal growth most of the time, that is, even these values would very likely make the lake more eutrophic than it actually is—if it weren't for Light limitation due to the lakes natural mineral turbidity!

Just FYI—

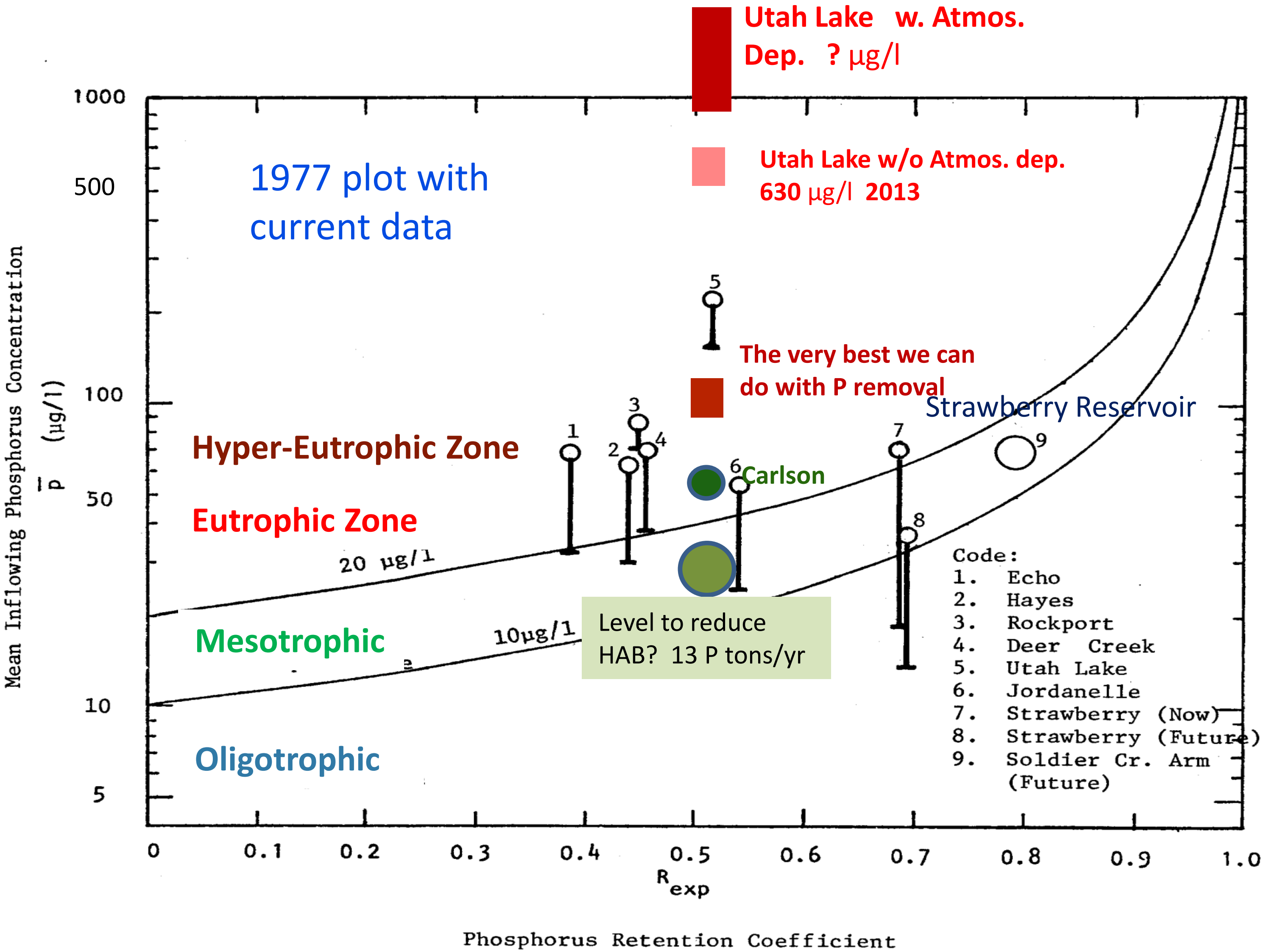
How about controlling algal blooms, including Harmful Algal Blooms (HAB) via P removal?

—To limit algal growth to a low level, < 10 µg/l in-situ
(at the beginning of the summer growth season.)

—To limit to moderate algal blooms, < 20 µg/l in-situ

But Mother Nature is providing some 40+ µg/l nearly all of the time
and the sediments contain an essentially unlimited repository–

Take Away—
It is very unlikely algal growth can be significantly reduced via nutrient control/removal!



Predicted Trophic State based on the Larsen-Mercier Model

Conclusions:

1. Light-limitation likely limits algae in Utah Lake to an overall natural, moderately eutrophic condition.

2. Phos. loading to the lake is, as a minimum, at least 15 times larger than needed to support its natural eutrophic level and can't be made limiting to overall algal growth.

3. Nitrogen loading is also many times larger than a eutrophic level and can't be made limiting to overall algal growth but if N is reduced it might result in increased HABs.

4. It is appears that removal of even 90-95% of the P coming from WWTPs plus all feasible remaining 'surface' loads would not significantly lower the lakes natural eutrophic algal-growth level.

5. Though impossible, if P from all external sources were completed banished, P from the bottom sediments would likely provide the P needed for eutrophic-level algal growth.

6. Atmos. Deposition alone is likley adding far more than enough P & N to provide eutrophic loadings to the lake.

7. Phos. in the Upper Jordan River is moderate (about 50-60 µg/l). It cannot be reduced since it is likely not determined by the amount of P coming into the lake but by natural in-lake biological cycles and chemical-solubility conditions.

Bottomline:

It is very likely that Utah Lake would be the same algal-growth quality as now, even if every nutrient source were reduced to the highest degree possible—costing many hundreds of millions of dollars.

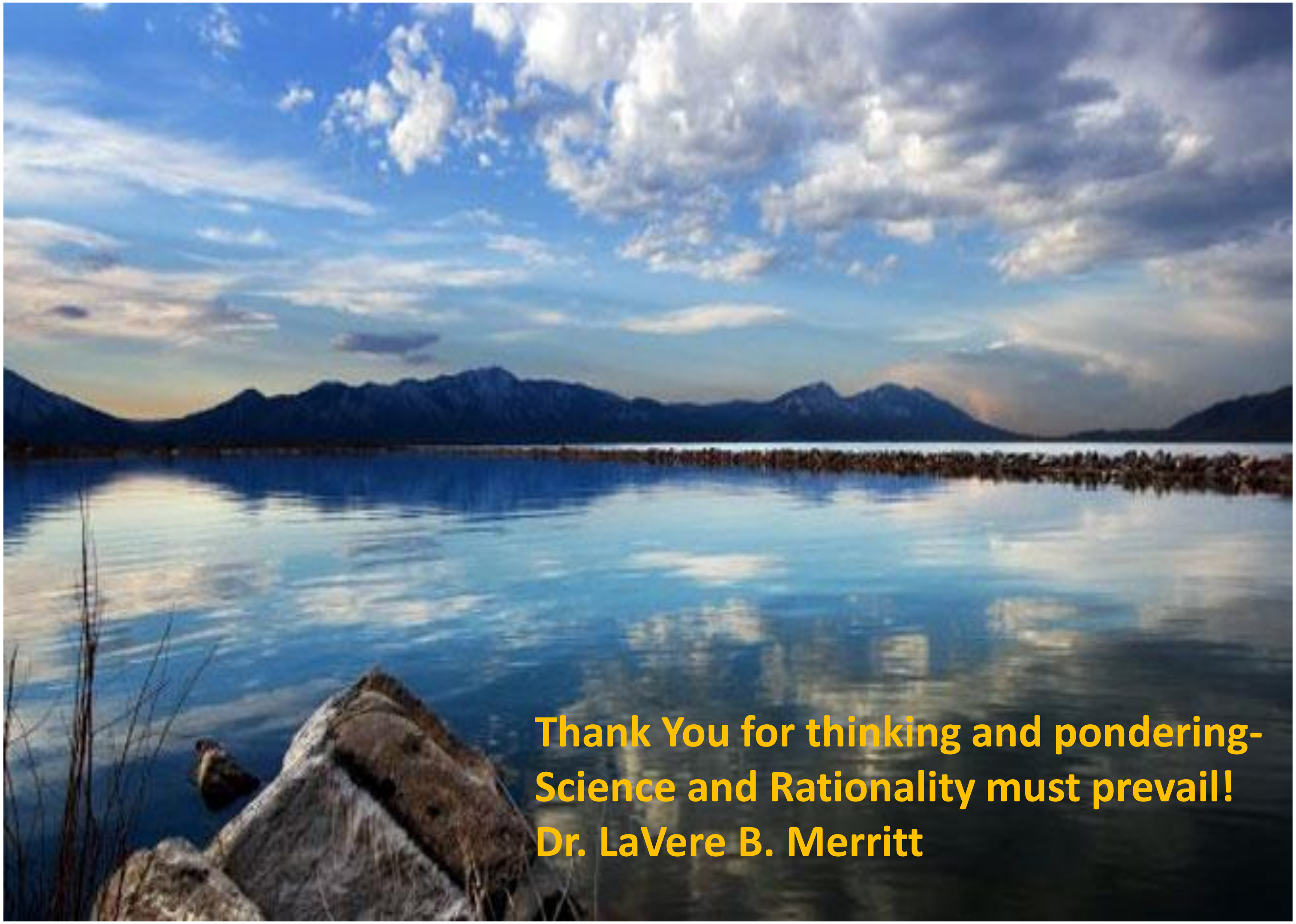
We would simply be paying a gigantic price to remove phosphorus that is now removed free by mother nature!

Postscript:

Similar scenarios exist for most of the valley-basin waters of Utah.

- *The receiving waters are naturally nutrient-rich and overall algal growth is largely determined by factors other than nutrients (flow time and turbidity)!*
- *Therefore It's very unlikely that a significant improvement in receiving water quality would result from even the most advanced nutrient removal at most of Utah's WWTPs.*

Huge Issue: Do we want to spend many hundreds of millions of dollars in a full-scale experiment to see if nutrient removal at WWTPs might significantly reduce algae in their receiving waters? My research and long experience says: In most cases in Utah it will not and is/would be a gigantic waste of our citizens' money!


Thank You for thinking and pondering-
Science and Rationality must prevail!
Dr. LaVere B. Merritt